EMPIRICAL STUDY OF MUSCLE FATIGUE FOR DRIVER'S ERGONOMIC ANALYSIS DURING PROLONGED DRIVING

BY

NOOR AZLYN BINTI AB GHAFAR

A thesis submitted in fulfillment of the requirement for the degree Master of Science in Mechatronics Engineering

Kulliyyah of Engineering
International Islamic University Malaysia

FEBRUARY 2023

ABSTRACT

Driving has become essential in transporting people from one place to another. However, prolonged driving could cause muscle fatigue, leading to drowsiness and microsleep. Electromyography is an important type of electro-psychological signal that is used to measure electrical activity in muscles. This work classifies and predicts muscle fatigue from trapezius muscle of 10 healthy subjects. The EMG signals and the time when muscle fatigue was experienced by the subjects were recorded. The mean frequency and median frequency of the EMG signals were extracted. For classification of muscle fatigue in non-fatigue and fatigue condition, six machine learning models were used: Logistic Regression, Support Vector Machine, Naïve Bayes, k-nearest Neighbour, Decision Tree and Random Forest. From the value of median frequency and slope coefficient of median frequency, mathematical model was developed with respect to driver's physical factors. The results show that both the median and mean frequency are lower when fatigue conditions exist. In term of the classification performance, the highest accuracy for classifying muscle fatigue due to prolonged driving was obtained by the Random Forest classifier with 85.00%, using both the median and mean frequency of the EMG signals. This method of using the mean and median frequency will be useful in classifying driver's non-fatigue and fatigue conditions and predict muscle fatigue during prolonged driving. The significant factor influencing muscle fatigue of the driver was BMI. This study successfully developed mathematical model of second order polynomial of muscle fatigue and BMI (p<0.05 and the R^2 = 0.85). The model was successfully validated where the residual errors compared between predicted values and actual values were less than 10%.

ملخص البحث

أصبحت قيادة المركبات امراً ضرورياً في نقل الأشخاص من مكان إلى آخر، إلا أن القيادة لفترات طويلة قد تسبب تعبًا في العضلات مما يؤدي إلى النعاس او الغفوة القصيرة. يعد تخطيط كهربية العضل (EMG) نوعًا مهمًا للإشارة النفسية الكهربائية المستخدمة في قياس النشاط الكهربائي في العضلات. تصنف هذه الدراسة وتتنبأ بجُهد عضلة من عضلات شبه منحرفة لعشرة أشخاص أصحاء. تم تسجيل إشارات تخطيط كهربية العضل (EMG) والوقت الذي عانى فيه الأشخاص من التعب العضلي، واستخراج متوسط التردد ووسيط التردد للإشارات تخطيط كهربية العضل (EMG). ولتصنيف تعب العضلات في حالة عدم الإرهاق والتعب تم استخدام ستة نماذج للتعلم الآلي وهي: الانحدار اللوجستي Logistic Regression، وآلة المتجهات الداعمةSupport Vector Machine ، وبيز ساذج Naïve Bayes والجار الأقرب لنقطة الاختبار KNN وشجرة القرارات Decision Tree ومصنف الغابة العشوائية Random Forest. من قيم متوسط التردد ومعامل الانحدار لمتوسط التردد تم تطوير نموذج رياضي متعلق بالعوامل الفيزيائية للسائق. أظهرت النتائج أن كلاً من متوسط التردد ووسيط التردد يكونوا أقل عند وجود حالات التعب. ومن حيث أداء التصنيف، تم الحصول على أعلى دقة في تصنيف التعب العضلي بسبب القيادة الطويلة بنسبه 85% ذلك بواسطة نموذج Random Forest ونتائج متوسط التردد و الوسيط لإشارات تخطيط كهربية العضل(EMG) . أن هذه الطريقة سوف تكون مفيدة في تصنيف حالات عدم إرهاق السائق وتعبه، وستمكن من التنبؤ بإجهاد العضلات أثناء القيادة لفترات طويلة. في هذه الدراسة كان العامل المهم هو مؤشر كتلة الجسم (BMI) الذي يؤثر على تعب عضلات السائق. نجحت هذه الدراسة في تطوير نموذج الرياضي من الدرجة الثانية متعدد الحدود لإرهاق العضلات ومؤشر كتلة الجسم بمقياس (P <0.05) و (R^2 = 0.85). تم التحقق من صحة النموذج بنجاح حيث كان معامل الخطأ المتبقي مقارنة بين القيم المتوقعة والقيم الفعلية اقل من 10٪.

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion, it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Master of Science in Engineering.

DR. NUR LIYANA AZMI
Assistant Professor
Department of Mechatronics Engineering
Kulliyyah of Engineering
International Islamic University Malaysia

…………………………………
Nur Liyana Azmi
Supervisor

DR. KHAIRUL AFFENDY MD NOR
Assistant Professor
Department of Mechatronics Engineering
Kulliyyah of Engineering
International Islamic University Malaysia

…………………………………
Khairul Affendy Md Nor
Co-Supervisor

DR. NOR HIDAYATI DIYANA NORDIN
Assistant Professor
Department of Mechatronics Engineering
Kulliyyah of Engineering
International Islamic University Malaysia

…………………………………
Nur Hidayati Diyana Nordin
Co-Supervisor

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Master of Science in Engineering.

PROF IR DR SITI FAUZIAH TOHA
Department of Mechatronics
Faculty of Engineering
International Islamic University Malaysia
PE NO. P117184

…………………………………
Siti Fauziah Toha @ Tohara
Internal Examiner

…………………………………

External Examiner

This thesis was submitted to the Department of Mechatronics and is accepted as a fulfilment of the requirement for the degree of Master of Science in Engineering.

……………………………….
Ali Sophian
Head, Department of Mechatronics

This thesis was submitted to the Kulliyyah of Engineering and is accepted as a fulfillment of the requirement for the degree of Master of Science in Engineering.

……………………………….
Sany Izan Ihsan
Dean, Kulliyyah of Engineering

DECLARATION

I hereby declare that this thesis is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

Noor Azlyn Ab Ghafar

Signature…………………………… Date…10-Feb-2023……………

INTERNATIONAL ISLAMIC UNIVERSITY MALAYSIA

DECLARATION OF COPYRIGHT AND AFFIRMATION OF FAIR USE OF UNPUBLISHED RESEARCH

EMPIRICAL STUDY OF MUSCLE FATIGUE FOR DRIVER'S ERGONOMIC ANALYSIS DURING PROLONGED DRIVING

I declare that the copyright holder of this thesis are jointly owned by the student and IIUM.

No part of this unpublished research may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording or otherwise without prior written permission of the copyright holder except as provided below

1. Any material contained in or derived from this unpublished research may only be used by others in their writing with due acknowledgement.

2. IIUM or its library will have the right to make and transmit copies (print or electronic) for institutional and academic purpose.

3. The IIUM library will have the right to make, store in a retrieval system and supply copies of this unpublished research if requested by other universities and research libraries.

By signing this form, I acknowledged that I have read and understand the IIUM Intellectual Property Right and Commercialization policy.

Affirmed by Noor Azlyn Ab Ghafar

……………………………… ……………………..
Signature 10-Feb-2023 Date

This thesis is dedicated to my late father, mother and husband for laying the foundation of what I turned out to be in life.

ACKNOWLEDGEMENTS

All glory is due to Allah, the Almighty, whose Grace and Mercies have been with me throughout the duration of my programme. Although, it has been tasking, His Mercies and Blessing on be ease the herculean task of completing this thesis.

I am most indebted to by supervisor, Dr Liyana Azmi whose enduring disposition, kindness, promptitude, thoroughness and friendship have facilitated the successful completion of my work. I put on record and appreciate her detailed comments, useful suggestion and inspiring queries which have considerably improved this thesis. Her brilliant grasp of the aim and content of this work led to her insightful comment, suggestions and queries which helped me in great deal. Despite her commitments, she took time to listen and attend to me whenever requested. The moral support she extended to me is in no doubt a boost that helped in building and writing the draft of this research work. I am also grateful to my co-supervisor, Dr Khairul Affendy Md Nor and Dr Nor Hidayati Diyana Nordin whose support and cooperation contributed to the outcome of this work.

Lastly, my gratitude goes to my beloved husband and my loving mother; for their prayers, understanding and endurance while away.

Once again, I glorify Allah for His endless mercy on me of which is enabling me to successfully round off the efforts of writing this thesis. Alhamdulillah.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

EMG	Electromyography
MNF	Mean Frequency
MDF	Median Frequency
BMI	Body Mass Index
YOD	Years of Driving
SENIAM	Surface EMG for Non-Invasive assessment of Muscle
H_0	Null Hypothesis
H_a	Alternative Hypothesis
ANOVA	Analysis of Variance
MVC	Maximum Voluntary Contraction
UAV	Unmanned Arial Vehicle
SVM	Support Vector Machine
kNN	k-Nearest Neighbor

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

Road transportation is one of the major modes of transportation used by Malaysians. Driving has become more important because it a is fast, cheap, and practical way of moving people from one place to another (Kamat et al. 2020). According to a Ministry of Transport Malaysia (MOTM) report, the number of register vehicle recorded in 2020 was 32.28 million. In 2021, the number had increased to 33.57. In addition, car have been recorded as the type of vehicle used most frequently by Malaysian with a rate of 47.10% followed by motorcycle at a rate of 46.19 in 2021 (MOTM 2022).

As a developing country, Malaysia gains income from greater productivity, and at the same time requires people to move faster and further (Sanjaya, Lee, and Katsuura 2016). Therefore, the transportation system of roads and highways should be greatly improved, which will enable Malaysians to experience better infrastructure, facilities and comfort. Although the increase in driving activity offers major benefits, it also has negative effects due to the increasing number of road accidents (Ani, Kamat, and Husin 2017). Malaysia has one of the highest rates of road accidents worldwide in relation to its population. Since 2012 to 2018, Malaysia has been ranked as the seventh-highest country in the world for the overall number of traffic accident. Additionally, Malaysia has had the greatest global mortality per 100,00 people since 1995 (Wan Husin et al. 2021).

In 2019, the Road Safety Department of Malaysia recorded 5764 cases of fatal accidents (Mahat, Jamil, and Sarah Raseli 2020). The three main causes of traffic accidents are human, environmental, and technical factors (Hawa Harith and Mahmud

2018). According to Malaysian Institute of Road Safety Research (MIROS) reported that the main contributor to road accident is human factor as much as 80% (Shariff et al. 2022). Mahat et al. (2020) categorized human factor into subfactor and according to their finding, the first ranking is drunk driving while drowsiness or microsleep rank as second factor contributing to road accident (Mahat et al. 2020). Fatigue is one of the factors leading to microsleep or drowsiness of the drivers besides prolonged driving, road condition, environment and health (Zaleha et al. 2021).

Research defines fatigue as a lack of ability to exert additional force or power (Al-Mulla, Sepulveda, and Colley 2011). Fatigue detection is important in many areas such as the health sector to monitor health and welfare of the patients. For example, electromyography (EMG) is implemented in the use of prosthetic control devices. Muscle tiredness detection and classification are also crucial in the fields of human-computer interactions, sports injuries and performance, and ergonomics. Muscle tiredness is one of the most common causes of injuries in athletes, and it is usually identified after the muscle has already been injured. (Freitas 2008). When muscular exhaustion is not diagnosed early enough, it can cause pain and also financial hardship. In addition, the most expensive therapy in this world according to Tlili et al., (2021) is spinal therapy (Tlili et al. 2021). As a result, detecting muscular exhaustion before it becomes obvious is critical.

Driving on the highway involves a monotonous driving environment because of the wide and flat pavement, fewer spatial references and high volume of traffic (Fu, Wang, and Zhao 2016). Prolonged driving in this type of environment requires drivers to sustain attention over long a period which decreases their alertness performance and lead to fatigue.

An important measure in the ergonomics of car seats during driving is the selection of the seat inclination angle to increase the driver's comfort, reduce fatigue, and avoid musculoskeletal disorders (Ferrari and Croft 2001). Selection of seat inclination angle will affect the spine posture of the driver especially during prolonged driving. The weight distribution supported by the seat-pan and backrest, as well as the boundary condition of upper body vibration and the spine’s curvature, are expected to change when sitting with an inclined backrest (Liu and Qiu 2021).

This study classifies EMG signal of non-fatigue and fatigue condition of the driver during prolonged driving using Machine Learning technique. In addition this work also develops a mathematical model to find the relationship between driver’s physical factors and muscle fatigue during prolonged driving. According to J. Barbosa (2003), the definition of a mathematical model is the behavior of real devices and objects is represented mathematically. Modeling a device or system is essential for both engineers and scientists. The mathematical model developed needs to be validated to ensure that the model is accepted.

This study is significant in detecting and predicting muscle fatigue. In addition, this study will also reveal the relationship between physical factor of the driver and muscle fatigue so that drowsiness and microsleep can be prevented. This study focuses to monitor the muscle activity of the subject using EMG signal which it aimed to prevent musculoskeletal disorder in a longer time. In directly, the risk and number of accidents associated with driving fatigue can be minimized. In addition, this study will also reveal the relationship between physical factor of the driver and muscle fatigue.

1.2 PROBLEM STATEMENT

In the recent year, several advanced signal processing algorithms and machine learning methods have been used in the researches (Karthick, Ghosh, and Ramakrishnan 2018). For the classification of non-fatigue and fatigue condition of the driver, several methods had been proposed previously using different classification techniques and different psychophysical signal (Bhardwaj, Natrajan, and Balasubramanian 2018). To date, Machine Learning classification of muscle fatigue using EMG has mainly focused on the areas of rehabilitation, sports science, human-computer interaction and medical research. However limited research had been conducted in the field of driving.

In addition, it is important to relate the physical factor affecting muscle fatigue of the driver during prolonged driving in order to prevent musculoskeletal injury and accident due to fatigue. Ani et al., (2017) developed and validated a mathematical model of driver fatigue using driving duration, road type, gender, the relation between gender and road type, as well as the relation between driving duration and road type as the input parameters (Ani et al. 2017). Meanwhile Fu et al. (2016) developed a mathematical model based on the Hidden Markov Model (HMM) that used EMG, Electroencephalograms (EEG), and respiration signals, as well as contextual information such as the driver's sleep quality, driving conditions, and circadian rhythm (Fu et al. 2016). Lastly, Wang et al. (2017) developed a model for driver fatigue based on ECG and EMG data using non-contact sensors (Wang, Wang, and Jiang 2017). Currently, less research has been undertaken to develop a mathematical model based on the physical factors of body mass index (BMI), age, and years of driving (YOD) to determine muscle fatigue during driving.

1.3 OBJECTIVE OF THE RESEARCH

The objectives of this research are:

1. To classify non-fatigue and fatigue conditions of the driver during prolonged driving using electromyography (EMG) signal.
2. To identify significant physical factors (body mass index (BMI), age, and years of driving) related to muscle fatigue of the driver during prolonged driving.
3. To formulate and validate the mathematical model of muscle fatigue with respect to the driver's physical information.

1.4 SIGNIFICANCE OF THE RESEARCH

To date, muscle fatigue classification has mainly focused on the areas of rehabilitation, sports science, human-computer interaction and medical research. However, limited research on muscle fatigue classification has been conducted in the field of driving using EMG and Machine Learning. This is an important topic as driving fatigue leads to accidents and loss of life. In terms of modeling muscle fatigue, less research is done on modeling muscle fatigue with respect to driver's physical factors. This research is able to classify the muscle fatigue during prolonged driving. This research has also developed and validated the mathematical model of muscle fatigue and drivers' physical factors during prolonged driving.

1.5 SCOPE OF THE RESEARCH

This research is divided into two parts: experimental and mathematical modeling. In the experimental part, an EMG sensor was used in this research to study the muscle activity of the driver. The EMG signal was measured using BITalino biosignal acquisition board. The EMG signal was further pre-processed using MATLAB software. The targeted muscle was the trapezius (shoulder) muscle. Ten healthy subjects with age between 20 and 40 years old were recruited. The subjects needed to drive a car for 2 hours using a highway route. The road condition is monotonous and the experiment took place at the East Coast Expressway Phase 2, Malaysia. The type of car used in this experiment was Perodua Axia with automatic transmission. The seat inclination angle was set to 10°. All subjects needed to maintain a driving speed of 90km/h during the experiment.

The EMG signal was used to classify non-fatigue and fatigue condition of the driver using six Machine Learning algorithms namely: Logistic Regression, Support Vector Machine, Naïve Bayes, k-nearest Neighbour, Decision Tree and Random Forest. In the mathematical modeling part, the classification of muscle fatigue was carried out using Analysis of Variance (ANOVA) analysis. The most significant parameter was identified and the mathematical model developed was validated by calculating the residual error.

1.6 CONTRIBUTION OF THE RESEARCH

This research successfully classified the muscle fatigue condition of the trapezius (shoulder) muscle during prolonged driving. The relationship between muscle fatigue and the parameters was analyzed. Based on the results, the BMI of the subject contributed the most to muscle fatigue. A mathematical model of second-order polynomial using BMI and muscle fatigue of the driver during prolonged driving was successfully developed. The model was validated by calculating the residual error. Two sets of journal articles were successfully published throughout this work. First, a journal article entitled "Mathematical Model of Physical Factor for Driver Fatigue during Prolonged Driving" was published by Journal of Engineering and Technology (JET). Secondly, a journal article entitled "Classification of Muscle Fatigue during Prolonged Driving" was published by ELEKTRIKA, Journal of Electrical Engineering.

1.7 ORGANIZATION OF THE THESIS

This thesis consists of five main chapters.

Chapter 1 explains the background of this research, problem statement, objectives, and scope of the research. This chapter also explains the significance of this research and the publications that have been produces so far.

Chapter 2 presents the literature review of previous research to obtain important technical and scientific knowledge related to this research.

Chapter 3 explains the methodology of this research in detail which consists of participants, experimental procedure, data processing, classification and regression with the aid of a flowchart.

Chapter 4 presents and discusses all results of EMG data processing, classification of non-fatigue and fatigue conditions of the drivers and regression to develop a mathematical model based on the significant physical parameter of the drivers. All findings of this research are highlighted in this chapter.

Chapter 5 presents the conclusion of the research and recommendations for future work.